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The EU Nitrate Directive and CAP Reform

Effects on Agricultural Production, Trade, and Residual Soil Nitrogen

Dale Leuck
Stephen Haley
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Brad McDonald

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The EU Nitrate Directive and CAP Reform: Effects on Agricultural Production, Trade, and Residual Soil Nitrogen. By Dale Leuck, Stephen Haley, Peter Liapis, and Brad McDonald. Commercial Agriculture Division, Economic Research Service, U.S. Department of Agriculture. Foreign Agricultural Economic Report No. 255.

Abstract

When fully implemented, the European Union's Nitrate Directive could be more effective than other policies in reducing nitrate pollution and targeting reduction to areas where most needed, usually areas of intensive livestock production. The European Union (EU) Nitrate Directive, passed into legislation in 1991, limits the net delivery of nitrogen to the soil beginning in 1999. The Directive may reduce production 8 percent for dairy, 5 percent for beef, 10 percent for poultry and eggs, and 12 percent for pork. The MacSharry Plan for Common Agricultural Policy (CAP) reform could more significantly reduce EU crop production than either the Nitrate Directive or a hypothetical 50-percent fertilizer tax. In general, input usage could increase under the Nitrate Directive and decrease under CAP reform and the fertilizer tax. The delivery of nitrogen to the soil could be most reduced with a fertilizer tax, but this reduction would be from commercial fertilizer rather than livestock manure and therefore may not occur in the regions where nitrate pollution is most severe. CAP reform could most significantly affect EU exports, world trade, and U.S. imports.

Keywords: CAP reform, environmental policies, European Union, fertilizer, manure, nitrate, nitrate directive, nitrogen tax, trade.

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Summary

Agriculture as a source of pollution emerged as a political issue in the European Union (EU) as scientific evidence of farming's effects on the environment mounted throughout the 1980's. The two farming practices that most concern policymakers are the use of large amounts of fertilizer for crop growth and the disposal of livestock manure. Both materials are sources of nitrogen, which is transformed into nitrate once in the soil. Nitrate that is not used by plants or transferred back into the atmosphere leaches through the soil or runs off into water supplies. High levels of nitrate in water may adversely affect human health as well as the metabolism of livestock.

In response to high nitrate levels in water supplies, the EU passed its Nitrate Directive in 1991. The Directive's objective is to limit the amount of nitrogen remaining in the soil as a residual after uptake by crops to 170 kilograms per hectare (kg/ha) in yet-to-be-defined "vulnerable zones." Other regulations on the use of nitrogen fertilizer, the numbers of livestock, and the storage and disposal of manure are to be defined and implemented over an 8-year period.

This report presents the results of a study that compared the two policies that could reduce nitrates--the Nitrate Directive and the MacSharry proposal for reform of the Common Agricultural policy (CAP)--with a hypothetical fertilizer tax.

The most severe nitrate problems appear to be in Denmark, Belgium, and The Netherlands the study finds. Limiting the amount of residual nitrogen in these countries to 170 kg/ha would require decreases in livestock numbers of 9, 28, and 65 percent. Fertilizer use would probably have to be reduced 2 percent in Denmark and 28 percent in The Netherlands. Sufficient potential for increased fertilizer efficiency and substitution of manure for fertilizer exists, such that no decrease in crop yields need occur. More effective methods of storing and disposing of manure could substitute for some of the reduction in fertilizer use and livestock production.

The study shows that delivery of nitrogen to the soil would be reduced the most with a fertilizer tax. However, such a tax would only slightly reduce crop production and therefore may not sufficiently reduce nitrate pollution where it is most needed, which is in regions of intensive livestock production. Only a policy targeted at the livestock sector may reduce nitrate pollution to desired levels where needed. The Nitrate Directive may accomplish this by reducing livestock production.

Under CAP reform, crop and beef production decline, but pork and poultry production increase and dairy production remains stable. Therefore, CAP reform would not reduce residual nitrogen levels in intensive livestock areas as much as the Nitrate Directive.

Under the Nitrate Directive, the EU could become a net importer of livestock products except beef, export more wheat and coarse grains, and import less corn and oilseeds. While the analysis shows increases in world livestock and corn prices, U.S. oilseed producers would export less at lower prices.

Under CAP reform, pork and poultry production would increase and crop production would decrease. Exports of pork and poultry are shown to increase, wheat and coarse grain exports to decline, and imports of corn and oilseeds to increase. World prices would increase for all products except pork and poultry, which would allow the United States to export more of the higher priced products.

According to the study, the combination of the Nitrate Directive and CAP reform reduces both livestock and crop production in the EU. World livestock prices generally increase the most in this scenario, but world crop prices increase less than under CAP reform alone because of lower EU feed demand. The combined policies would affect U.S. livestock trade in ways similar to the Nitrate Directive, with the exception of pork. U.S. grain exports are shown at levels between the Nitrate Directive and CAP reform.

The EU Nitrate Directive and CAP Reform

Effects on Agricultural Production, Trade, and Residual Soil Nitrogen

Dale Leuck, Stephen Haley, Peter Liapis, and Brad McDonald

Introduction

Several policy changes in the European Union (EU) may affect EU agricultural production, resource use, water quality, and world trade and prices. These changes include reform of the Common Agricultural Policy (CAP), adopted by EU Agricultural Ministers in May 1992, and the EU Nitrate Directive, adopted by EU Environmental Ministers in June 1991. Both policies are to be phased in over the next several years.

The CAP has provided commodity prices to EU farmers that have been both higher and more stable than world prices for more than 30 years. During this time, EU agricultural production increased, partly because of the level and stability of prices, with the resulting surpluses requiring export subsidies for their disposal onto world markets (Commission of the European Communities, July 1991). CAP reform is intended to reduce the financial costs of disposing of these surpluses by gradually reducing EU commodity prices and limiting production. The 1992 CAP reform proposals reduce EU crop and livestock production and significantly affect world trade (Helmar and others, 1994), as do proposals to reform the CAP within the context of world trade (OECD, 1987; Roningen and Dixit, 1989; Tyers and Anderson, 1986).

Increased agricultural production has been achieved primarily through using more inputs on a slightly decreased area, thus leading to higher amounts of chemicals that pollute water supplies (Manale, 1991; Agra Europe, 1991). Nitrogen from livestock manure and nitrogen fertilizer is turned into nitrate once applied to fields, and some of it runs off or leaches into water supplies. Nitrate may be harmful to the health of both humans and livestock when ingested above certain levels (Garner, 1958; Mirvish, 1991; Walton, 1951). The EU Nitrate Directive is intended to improve the quality of EC water supplies by limiting annual amounts of residual nitrogen, which is nitrogen applied to fields in excess of uptake by crops.

Livestock production and/or fertilizer use may have to be reduced to meet the goals set by the Nitrate Directive. Imposing limits on the numbers of animals in certain areas, such as already exist in parts of northern Europe, may reduce livestock production. An EU-wide tax on nitrogen fertilizer use may most effectively limit fertilizer use. Reduced fertilizer use may, in turn, reduce crop production.

Both CAP reform and environmental policies, such as the Nitrate Directive and a fertilizer tax, may reduce EU agricultural production as well as nitrate delivery to the environment. However, only limited research has looked at the effects of possible CAP reforms on water quality or the effects of environmental policies on European agriculture (Abler and Shortle, 1992; Hanley, 1990). It is unclear to what degree these policies may conflict or mutually reinforce each other. This paper therefore analyzes the effects of CAP reform, the Nitrate Directive, and a 50-percent tax on nitrogen fertilizer on residual nitrogen, EU agricultural activities, and world markets.

The report is divided into six sections. The first section describes how nitrate both benefits agriculture and hurts water quality. The second section discusses the contribution of intensive agriculture, and especially livestock production, to the nitrate pollution of water in the EU.[1] In the third section, the Nitrate Directive and the MacSharry proposal for CAP reform are summarized. Possible implications of the Nitrate Directive for manure disposal, livestock production, and fertilizer use are calculated in the fourth section.

[1] This report covers only 10 countries of the EU: Belgium, Luxembourg, Greece, Denmark, Germany, France, Ireland, Italy, The Netherlands, and the United Kingdom. Although agriculturally induced water pollution is increasing in Spain and Portugal, the problem in these countries is relatively moderate.

Previous efforts to model the effects of environmental policies on production, trade, and residual nitrogen are summarized in the fifth section. The trade model used to compare the effects of the Nitrate Directive, a fertilizer tax, and CAP reform on agricultural activities is also summarized in that section. Finally, the results of various policy alternatives on nitrogen balance, production, trade, and world prices are discussed in the last section.

Nitrate in the Environment[2]

Nitrate is derived from atmospheric nitrogen. The most important sources of nitrate are commercial nitrogen fertilizers and livestock manure.[3] The nitrogen contents of fertilizer and manure are transformed into nitrate once they have been applied to fields. Other sources of nitrate are industrial pollution, automobile exhausts, and electrical storms, and are delivered to the soil by (acid) rainfall. Plant wastes are also a significant source of nitrogen, and sewage sludge has become a more common source in recent years.

Nitrate is the form of nitrogen that can be directly absorbed by plants and is essential for plant growth. The organic compounds that make up a plant, such as proteins and enzymes, depend on nitrate for their development. Some of these compounds give plants their green color and aid in photosynthesis, the process by which plants grow. Plants, however, cannot absorb 100 percent of the nitrate in the soil, and some nitrate eventually enters ground or surface water by leaching or runoff.

Nitrate that enters ground or surface water contributes to excess nutrient levels in the water, known as eutrophication. Excess nutrients in surface waters precipitate algae blooms, which, in turn, take oxygen out of the water. The algae blooms are malodorous and may be toxic if ingested. Moreover, the decreased oxygen content of the water destroys aquatic life. Phosphate from fertilizer has similar effects.

Nitrate, however, is especially harmful, because it may also hurt both livestock and human health. High levels of nitrate have long been known to interfere with the metabolism of livestock, leading to reduced feeding efficiency (Garner, 1958). The main human health concern with nitrate is its possible linkage to stomach cancer (Mirvish, 1991).

High nitrate levels may also cause methemoglobinemia in infants, a respiratory problem often referred to as "blue baby" syndrome. This occurs because nitrate is reduced to nitrite in the body and causes blood hemoglobin to be oxidized into ferric iron, which interferes with the body's ability to absorb oxygen.

Walton (1951) found no methemoglobinemia when drinking water contained less than 10 parts per million (ppm) of nitrate. A 2.3-percent and 17-percent rate of occurence was found when drinking water contained from 10 to 20 ppm and 20 to 40 ppm, with the remaining rates found in nitrate concentrations exceeding 40 ppm. Walton's findings were the basis for the World Health Organization and the United States Environmental Protection Agency recommendations that drinking water contain no more than 50 ppm of nitrate.

The structure of the soil (for example, sandy soil), its content of organic matter, the amount of rainfall, and the density of the plants influence the amount of nitrogen that is leached or runs off into water supplies as nitrate. Leaching may occur fairly rapidly under some conditions, but may take up to several decades under other circumstances. For example, in Europe, up to 50 percent of soil nitrate may leach into water supplies in regions having light, sandy soils, heavy rainfall, and a high water table (Agra Europe, 1991). This is within the range of estimates of nitrogen loss in a survey of studies by Scharf and Alley (1988).

Nitrogen also exits the soil through volatilization and denitrification. Sutton and others (1983) report that up to 30 percent of the nitrogen in manure spread on fields in Indiana (United States) may return to the atmosphere as nitrous oxides or atmospheric nitrogen through volatilization. Agra Europe (1991) states that losses into the atmosphere from manure may be up to 50 percent in Europe if the manure is not plowed under the soil. Some volatilization may also occur with fertilizer, particularly urea and ammonia, if not properly applied. Denitrification is a chemical reaction in the soil, whereby the nitrate and nitrite forms of nitrogen are reduced to more elemental forms, such as nitric oxide, nitrous oxide, and elemental nitrogen. These oxides may later be returned to earth through acidic deposition. Soil and weather factors influence the rates of volatilization and denitrification.

The EU Nitrate Situation

In the EU, surplus manure in regions of intensive livestock production is typically viewed as the cause of nitrate pollution. While residual nitrogen is also associated with fertilizer use, fertilizer is viewed as necessary for crop production, because it may be eco-

[2]A more detailed discussion of the role of nitrogen in the environment may be found in Follett and others (1981).

[3]While manure also functions as a fertilizer, this report distinguishes between manure and commercially produced fertilizer.

nomically pelleted, transported, and applied at optimum times during the growing season. Desired yields can be more accurately obtained from fertilizer, because its composition is more certain than that of manure (Legg and others, 1989). Farmers have also become more prudent in applying fertilizer in ways that increase the proportion that crops use and minimize the amount of runoff and leaching.

While nitrate pollution is more common in areas of intensive livestock production, it is also a problem in regions where horticultural commodities and grape vines are produced. These regions are not the focus of this study, however.

The disposal of livestock manure further aggravates any residual nitrogen in the environment coming from fertilizer. Livestock manure is often not applied with the same goal of efficiency as fertilizer, because manure is generally viewed as a costly waste that needs disposal, instead of as a source of nutrients that can be economically applied to crops. Part of the reason for this is the relatively high costs involved in handling and processing manure in a manner that can economically maximize its contribution to soil fertility.

Nitrate pollution therefore tends to be most severe in regions of intensive livestock production. In these areas, manure disposal adds significantly to residual nitrogen but plays a subordinate role, next to fertilizer, in contributing to crop fertility. Livestock production is thus often considered the source of nitrate pollution that needs control more than does fertilizer use.

Intensification of Agriculture and Nitrate Pollution

Increased intensification of agriculture refers to increased concentration and production of livestock and grain on roughly the same land area. The volume of manure has increased roughly in proportion to increased livestock production. EU production of dairy products, beef, and veal has more than doubled since 1950, while pork and poultry production more than tripled. EU egg production has increased more slowly. The growth in livestock production was especially rapid in some regions, where it has caused particularly significant nitrate pollution problems.

·Agra Europe (1991) describes current nitrate pollution in the EU as covering most of Belgium and The Netherlands, parts of Germany, the Brittany region of France, the Po valley of northern Italy, and several regions of southern England (fig. 1). The majority of manure is from cattle and pigs. Both Belgium and The Netherlands have more cattle and pigs on their utilizable agricultural area (UAA) than do other EU countries (table 1). Germany and Denmark also have high densities of cattle and pigs, although Danish laws have reduced nitrate pollution in recent years.

Besides Belgium and The Netherlands, other shaded areas in figure 1 are also regions of relatively intensive livestock production. The number of animals per enterprise seems more indicative of nitrate problems than does the number of animals per hectare, because cost considerations mean that manure is generally disposed of within similar distances to the production facilities regardless of size. For example, while Germany averages 18 livestock units per farm, the state of Lower Saxony, which comprises much of the shaded area in the northwest of Germany, averages 26 livestock units per farm (de Haen and others, 1991). Rainelli (1991) notes that the Brittany region of western France accounted for 39 percent of intensive livestock output, by value, between 1983 and 1985. The Po valley is Italy's main agricultural region and contains many high-volume dairy and pig farms.

Grain production also increased to satisfy livestock demand and export markets. Higher yielding grain varieties were adopted, requiring more fertilizer to supply nutrients for plant growth, as well as herbicides, insecticides, fungicides, and other chemicals to minimize the influences of weeds, insects, and disease on plant development. Between 1960 and 1990, nitrogen use per hectare of UAA more than tripled, from about 30 kg to about 100 kg, while grain yields roughly doubled to 6 tons on a slightly smaller area (fig. 2).

Grain production is less concentrated than livestock production. However, grain is also produced in regions of intensive livestock concentration (fig. 1). Thus, both contribute to nitrate pollution, although livestock is viewed as the sector where controls are necessary because manure is viewed as a waste.

Several factors increased intensification of EU agriculture after World War II. Income growth increased demand for meat and dairy products. The CAP provided high and stable prices to encourage production. Technological advances were sufficiently important that de Witt (1988) argues they would have been a major factor in and of themselves. It is difficult to separate the effects of these factors on production because they occurred simultaneously. However, the CAP is the one factor amenable to government control for the purpose of reducing both production and pollution.

Figure 1

EU areas of surplus animal manure

Source: Agra Europe (1991).

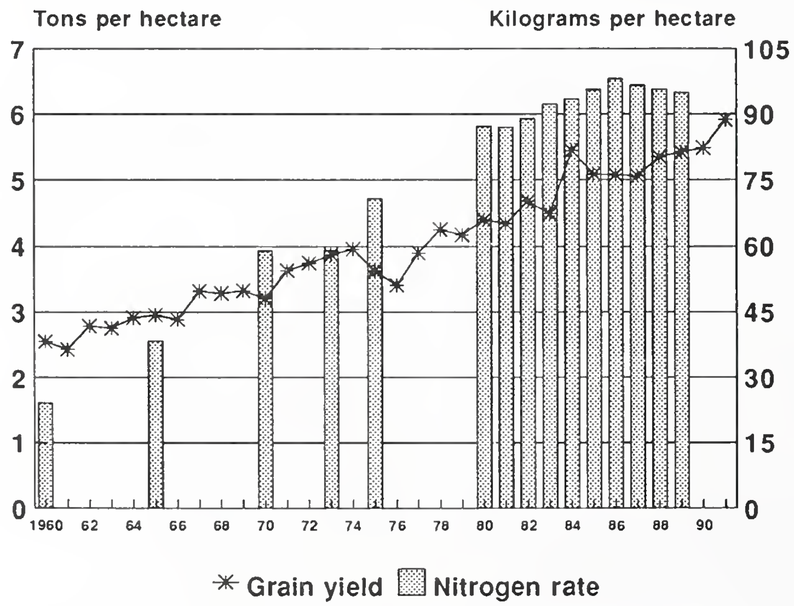
Table 1--Cattle and pigs per UAA for selected EU countries, 1989

Livestock	Belgium	The Netherlands	Denmark	Germany	France	Italy	United Kingdom
				Head			
Cattle	2.29	2.36	0.79	1.23	0.70	0.51	0.65
Pigs	4.75	6.80	3.27	1.90	.45	.54	.40

Source: Commission of the European Communities, *Agricultural Situation in the Community*, selected issues.

Figure 2

European Union: Fertilizer nitrogen rate and grain yield



Source: Commission of the EC; United Nations.

Concentration of Nitrate Levels in Water Supplies

Prompted by growing concern about nitrate in water supplies, the EU Drinking Water Directive was passed in 1980. This Directive established guidelines for nitrate levels in water consistent with recommendations made by the World Health Organization. The maximum allowable concentration (MAC) of nitrate in ground water recommended under the Water Directive is 50 ppm.

Annual residual nitrogen in Germany has increased from 10 kg/ha to more than 100 kg/ha in the last 20 years, with about 5 percent of delivered drinking water exceeding the MAC in the former West Germany (Agra Europe, 1991). Walther (1982) found nitrate concentrations in ground water in the Hildesheimer Boorde region of Lower Saxony ranging from 20 ppm to 90 ppm. His trend lines for selected wells indicated increases in nitrate levels ranging from 0.44 ppm to 1.86 ppm per year. Muller (1982) reports that 70 percent of analyzed wells along the Mosel River exceeded 50 ppm, with 40 percent having a concentration exceeding 100 ppm. The Mosel River valley is a wine-producing and horticultural region characterized by sandy soils and high fertilization.

While only about 2 percent of French citizens receive drinking water in excess of the MAC (Agra Europe, 1991), the problem is quite widespread in Brittany. Rainelli (1991) reports that the number of cantons (that is, counties) in Brittany where surface water exceeded the MAC increased from one to five between 1980 and 1990. In The Netherlands, the average nitrate concentration found in ground water 30 meters below sandy soils is 106 ppm (Manale, 1991).

It may take decades for excess nitrate to show up in water, thus these data understate the longer term nitrate problem. Nevertheless, currently measured nitrate levels are much higher in the EU than in the United States. As an example, nitrate concentration levels are much higher in some European rivers than in the Mississippi River in the United States (fig. 3), because some of the most intensive farming activities in the world exist in the EU.

Recent Changes in Livestock and Nitrate Levels

A number of policy reforms of the past decade may have reduced residual nitrogen from both livestock manure and fertilizer (Commission of the European Communities, *Agricultural Situation in the Community*, selected issues). Price support and intervention buying for grain have declined since the early 1980's. In 1988, a voluntary acreage set-aside program was established. Beginning in 1984, milk produced beyond a quota was charged a superlevy equal to 75 percent of the target price. This superlevy has since been increased to 115 percent of the target price.

The acreage set-aside and decreases in price supports have not yet reduced grain production in any EU country. Yields are likely to increase from new varieties of grain, leading to higher intensification on a slightly reduced area planted. Fertilizer use has remained about constant over the last several years.

The dairy quotas have reduced dairy cattle numbers and influenced the composition of cattle numbers. Between 1986 and 1991, dairy cattle numbers decreased by 12.5 percent in Belgium, 15 percent in Denmark, 17.8 percent in The Netherlands, and 13 percent in the other EC countries. Beef has not declined as much as dairy. Beef cattle numbers decreased by 1.8 percent in the EC and by 13.9 percent in Denmark. In Belgium and The Netherlands, beef cattle increased by 16 percent and 6.2 percent between 1986 and 1991. The cattle cycle has possibly not yet fully responded to the dairy quotas, however.

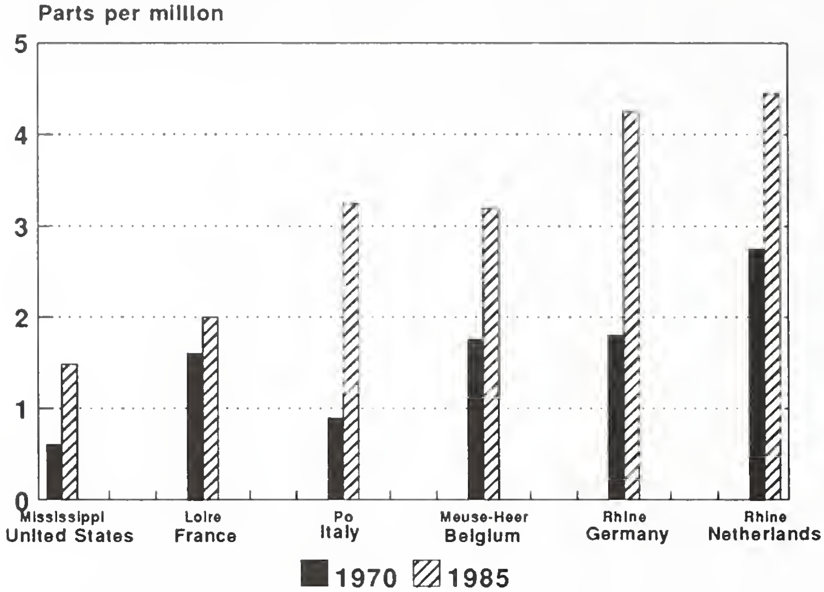
If other livestock had decreased by the same proportion as dairy, progress would have been made toward achieving the goals of the Nitrate Directive. However, nitrogen from increases in pork and poultry numbers more than offset the decrease in nitrogen from lower dairy and beef production in the EU. The amount of nitrogen from livestock manure in the EU countries increased slightly between 1986 and 1991, except in Denmark (table 2), where it decreased by nearly 3 percent. For Belgium and The Netherlands, nitrogen levels increased by 5.5 and 3.8 percent.

CAP Reform and EU Environmental Policies

Although CAP reform and the Nitrate Directive have different objectives, the effects of these factors on EU production and nitrogen balance may be similar. CAP reform will significantly reduce the system of support for both livestock and crop production. The 1992 CAP reform proposals have been shown to reduce both livestock and crop production (Helmar and others, 1994). Studies that analyzed a generic reduction in support in the context of world trade reform (OECD, 1987; Roningen and Dixit, 1989; Tyers and Anderson, 1986) found similar results. The EU Ni-

Figure 3

Nitrate concentration in selected rivers, 1970 and 1985



Source: Agra Europe (1991).

Table 2--Nitrogen from manure, 1986 base and 1991 levels

Year	Belgium	Denmark	The Netherlands	Other	Total EU
			1,000 tons		
1986 base	381	435	752	8,087	9,645
1991	402	422	781	8,209	9,815

Source: Leuck (1993).

trate Directive has set specific targets for reducing residual nitrogen. Achieving these targets may require reductions in livestock numbers and/or fertilizer use (and therefore possibly crop production).

Because both CAP reform and the Nitrate Directive are to be implemented, it is useful to analyze the effects of these policies on relevant variables, both separately and together. Reductions in livestock and/or crop production that differ substantially from the changes in agricultural production likely under CAP reform may achieve the Nitrate Directive's targets for residual nitrogen. Conversely, CAP reform may affect residual nitrate levels that fall short of the targets set by the Nitrate Directive. A separate analysis of these policies identifies these inconsistencies.

The EU Nitrate Directive

Several national policies have been enacted to limit nitrate pollution. However, international solutions will control nitrate pollution in the EU for two reasons. First, the pollution is manifest outside the region or country of its origin. Second, efforts by individual countries alone may place them at a competitive disadvantage by increasing their production costs.

The Nitrate Directive grew out of EU policies based on the more restrictive national policies. Discussion of national and EU policies may be found in Agra Europe (1991), Leuck (1993), and Manale (1991).

Responding to pressure from the EU Parliament, environmental groups, and some member governments, the EU Commission proposed legislation to reduce nitrate accumulation in ground and surface water. After 2 years of debate, the EU Council of Ministers passed the Nitrate Directive on June 14, 1991.

In its advisory role during the consultative reading, the Council of Agricultural Ministers suggested that compliance with the Directive be made voluntary. However, the Environmental Ministers decided that

compliance would be mandatory. Therefore, further debate may be expected between these two legislative groups as the details of the Directive are worked out.

While many important details are yet to be finalized, the general intent of the Nitrate Directive is to keep the nitrate levels in water from exceeding the MAC. Regions having excessive amounts of nitrate, known as "vulnerable" zones, were to have been designated by the member countries by the end of 1993. The member countries must also draw up "codes of good practice," which are required in the vulnerable zones but voluntary elsewhere. The minimum requirements for these codes are in the Directive, but member countries may legislate stricter codes if they desire. Member governments must maintain records of nitrate application in these zones.

After the vulnerable zones are designated, member countries have an additional 2 years in which to design specific programs to reduce nitrate levels to the MAC. These programs are to be implemented over an additional 4-year period. Thus, it will be 8 years before the requirements of the Nitrate Directive are fully implemented. The vulnerable zones will be reviewed every 3 years to take account of any changes that may affect their designation, such as changes in livestock density.

The Directive has several provisions to reduce nitrate leaching and runoff from manure. Although the provisions will have to be further clarified, they include periods when manure may be applied; regulation of manure application to waterlogged, sloping, flooded, frozen, or snow-covered ground; consideration of rainfall; and provisions for manure storage facilities.

The Directive also imposes an annual limit of 170 kg/ha, nitrogen equivalent, on the amount of livestock manure that may be applied after the 8-year period of transition. This limit is expressed in terms of manure because that is considered the major source of nitrate pollution. However, the directive also states that manure disposal be consistent with good agricultural practices in relation to the use of nitrogen by crops, the amount of nitrogen from chemical fertilizer and other sources, and the amount of nitrogen in the soil.

The text of the directive implies that both livestock manure and fertilizer be counted in calculating residual nitrogen. The 170 kg/ha is therefore interpreted as the maximum annual residual (MAR) nitrogen allowed by the Directive. The MAR thus includes nitrogen from both manure and fertilizer, less uptake by crops.

A Fertilizer Tax

Imposing a tax on fertilizer has often been proposed to reduce the threat of water contamination (Fleming, 1987; Weinschenck, 1987; Bonnieux and Rainelli, 1988) and to raise funds to cover the costs of processes to achieve pollution abatement (Bonnieux and Rainelli, 1988). Taxes are viewed as superior to direct controls on usage because the latter are more difficult to effectively implement on the nonpoint sources of pollution, such as nitrogen fertilizer (Pan, 1994). Such taxes conceptually could be set at a rate that equates with the monetary value of any environmental damage being caused. Then farmers could decide whether and how much to modify their practices in lieu of paying the tax (Reichelderfer, 1990).

Determining the optimum tax rate for agricultural pollutants is extremely difficult (Shortle and Dunn, 1986). This is partly because agricultural pollution is of the nonpoint source variety. When flows of pollutants come from nonpoint sources, it is difficult to monitor them accurately and thus to relate pollution to specific producers. Furthermore, it is often difficult to put a monetary value on the damage being caused.

Although a tax on nitrogen fertilizer has not been formally proposed, such a tax remains a possibility, because fertilizer contributes to nitrate pollution, particularly in regions with a high concentration of horticulture and winery. Furthermore, to the extent that fertilizer use must be reduced under the Nitrate Directive, a tax may be the most efficient means to accomplish such a restriction. It is therefore useful to analyze what effect a fertilizer tax might have on residual nitrogen and agricultural activities.

Any fertilizer tax is likely to be EU-wide. Individual countries have avoided imposing fertilizer taxes because of the effects they would have on competitiveness. With producer prices common across countries, the taxing of fertilizer in one country would cause effective financial support to decline in that country by increasing production costs. According to Harold (1992), the Danish Parliament was to impose up to a 150-percent nitrogen tax if consumption did not fall 30 percent over the 1987-90 period. That tax was not implemented because of its likely effects on Danish farmers' competitiveness.

The MacSharry Proposal for CAP Reform

The CAP reform package passed in May 1992 by the EU Council of Agricultural Ministers contains significant changes in EU agricultural policy (Madell, 1992). The reform package is based on proposals submitted to the EU Commission in June 1991 by EC Agricultural Minister Ray MacSharry. Although MacSharry's proposals were modified in subsequent debate, the resulting reform package of May 1992 is nevertheless sometimes referred to as the MacSharry plan. The reform package is planned for implementation over 3 years starting in 1993/94, and contains many specific features (Madell, 1992). The most important features of the MacSharry proposal are:

- Price supports are reduced:

  -grains intervention prices cut 30 percent;
  -oilseed price supports eliminated;
  -beef intervention prices cut 15 percent;
  -butter intervention prices cut, translated into a 3-percent cut in the price of cows' milk;
  -commodities not covered include cotton, rice, and sugar.

- Compensation for price reductions are made through direct payments:

  -45 ECU (European Currency Units) per ton for grains;
  -152 ECU per ton for oilseeds;
  -90 ECU per head for male beef cattle, paid at 10 months and 22 months of age, and 120 ECU per head for suckler cows.

- Payment is based on historical yields or herd size and requires current production.

- Farmers producing more than 92 tons of grain are required to set aside 15 percent of arable crop base.

Both CAP reform and a nitrogen tax directly affect the prices of agricultural commodities by specific magnitudes. Supply then responds in reaction to these price changes in ways that an accepted trade modeling framework can estimate. The Nitrate Directive, however, may restrict livestock numbers by magnitudes calculable outside the framework of a trade model. Secondary effects of the Directive on feed demand, net trade, and world prices are estimated with such a model later in this report, and compared with the effects of CAP reform and a nitrogen tax.

Implications of the Nitrate Directive for Manure Disposal, Livestock Production, and Fertilizer Use

By limiting the amount of residual nitrogen in the vulnerable zones, the Nitrate Directive implies possible reductions in livestock production and/or fertilizer use. Coefficients from Koopmans' (1987) study are used to calculate a nitrogen balance for each EU country for 1986. These coefficients measure the amount of nitrogen contained in different types of livestock manure and taken up by different kinds of crops (table 3). The nitrogen balances are then used to identify the countries where residual nitrogen exceeds the MAR, and to calculate the reduction in livestock production and fertilizer use needed to reduce residual nitrate to the MAR.

Nitrogen Uptake by Crops and Commercial Fertilizer Use

Two calculations of nitrogen uptake had to be inferred from information in the Koopmans study. First, the coefficient for the uptake of nitrogen by straw is assumed to equal 24.9 percent of the nitrogen uptake by all grains. Koopmans' calculation of nitrogen uptake by fodder (including hay, pasture, and silage) is unclear, and his data on area are much lower than those published in *Agricultural Situation in the Community* (Commission of the European Communities, selected issues). The procedure used in this study was to first apportion to individual countries of the EU the estimate of nonmarketable forage published in *Agricultural Situation in the Community*. This apportionment was based on the number of cattle and sheep (in terms of cattle units) in each country. Although strictly defined only for grass, the nitrogen coefficient from table 3 was then applied to these forage estimates to obtain the nitrogen content.

The estimated amounts of nitrogen from commercial nitrogen fertilizer, and the estimated uptakes of nitrogen by crops and forage are presented in table 4. About 11 percent of the nitrogen applied in the form of fertilizer in the EU was in excess of what crops and forage needed.

Nitrogen from fertilizer was in excess by 25 percent and 43 percent in Denmark and The Netherlands, but roughly equaled uptake in Belgium, Ireland, and Italy. A recent report (Agra Europe, 1991) indicates that the MAR will not be exceeded if the average application rate of nitrogen is less than 127 kg/ha.

Aggregate data conceal much of the nitrate problem, however. Most commercial fertilizers are not applied to forage. Therefore, most residual nitrogen from fertilizer is concentrated on crop acreage. Furthermore, this residual tends to be concentrated in regions of countries where relatively little forage and large amounts of crops are grown. Therefore, aggregate data understate the problem for these localized regions, except for small countries like The Netherlands, Belgium, and Denmark.

Nitrogen From Livestock Manure

About half of the nitrogen from manure comes from cattle, although this ratio varies from a low of 10 percent in Greece to peak at 69 percent in Ireland (table 5). Pigs dominate as the source of livestock nitrogen only in Denmark, but they are a major source of nitrogen in Belgium and The Netherlands. Sheep are a significant source of nitrogen in all countries except Belgium, Denmark, Germany, and The Netherlands. Nitrogen from poultry manure is small, compared with nitrogen from cattle, and is concentrated in France and the United Kingdom.

The amount of nitrogen from livestock manure totals nearly twice the amount of calculated uptake from forage. Therefore, even if the uptake from forage is underestimated, the addition of manure adds an amount of nitrogen that exceeds what crops can absorb in many countries.

Another way to view the nitrate situation is first to think of the EU as being about 11-percent excess in nitrogen from the 8.7 million tons of fertilizer application. An additional 9.6 million tons of nitrogen from livestock manure must then be accommodated. Except for France, each country must also accommodate an amount of nitrogen from livestock manure that slightly exceeds the amount of nitrogen from fertilizer (fig. 4). Thus, while manure is viewed as the source of the nitrate problem, commercial fertilizer evidently contributes nearly as much nitrogen to soil.

Reductions in Fertilizer Use and Livestock Production

The object of the Nitrate Directive is to reduce residual nitrogen levels to the MAR in regions where the MAR is exceeded. All countries in the EU have significant levels of residual nitrogen, although not all of them exceed the MAR. The 10.5 million tons of residual nitrogen in the EU represent about 57 percent of the total nitrogen applied (table 6). Nearly two-thirds of residual nitrogen in the EU is in Germany, France, and the United Kingdom.

Table 3--Nitrogen content of selected commodities[1]

Item	Wheat	Rice	Grains	Grass	Cattle	Pigs	Poultry	Sheep
	Percent				Kg/animal/year			
Nitrogen	1.9	1.3	1.5	3.0	64	13	0.48	20

[1]The nitrogen composition of crops and livestock may vary according to Sweeten (1992). The nitrogen composition of crops may vary because of variety and moisture, while the nitrogen content of manure depends upon feed composition, milk yield, and the weight to which the animal is fed.

Source: Koopmans, 1987.

Table 4--EU nitrogen uptake and commercial use, 1986

Country	Nitrogen uptake: All sources						Commercial nitrogen	
	Wheat	Coarse grains	Straw[1]	Rice	Forage	Total	Use	Residual
	1,000 metric tons							
Belgium/ Luxembourg	25	16	10	0	160	211	199	-12
Denmark	41	87	32	0	127	287	381	94
Germany	195	230	106	0	783	1,314	1,578	264
Greece	49	43	23	1	287	403	432	29
France	505	346	212	1	1,342	2,406	2,568	162
Ireland	8	23	8	0	368	407	343	-64
Italy	173	131	76	14	633	1,027	1,011	-16
The Netherlands	18	5	6	0	256	285	504	219
United Kingdom	263	159	105	0	995	1,522	1,671	149
Total	1,2774	1,040	578	16	4,951	7,862	8,688	999

[1]It is not clear if the coefficients for straw net out the nitrogen that is returned to the ground because of decomposition.

Source: Koopmans, 1987; United Nations, selected issues.

Only 18 percent of residual nitrogen is in Belgium, Denmark, and The Netherlands. However, Belgium, Denmark, and The Netherlands have residual amounts of nitrogen equal to 64 percent, 65 percent, and 77 percent of total nitrogen applied.

Belgium, Denmark, and The Netherlands are also the only countries that exceed the 170 kg/ha MAR, with residual nitrogen levels of 240 kg/ha, 187 kg/ha, and 480 kg/ha (table 6). To reduce the amount of residual nitrogen per hectare to the MAR, the amount of residual nitrogen would have to be reduced by 29 percent, 9 percent, and 65 percent in Belgium, Denmark, and The Netherlands. These reductions represent only 8 percent of the residual nitrogen in the EU, however.

The Nitrate Directive may ultimately result in one or more of several different policies to reduce residual

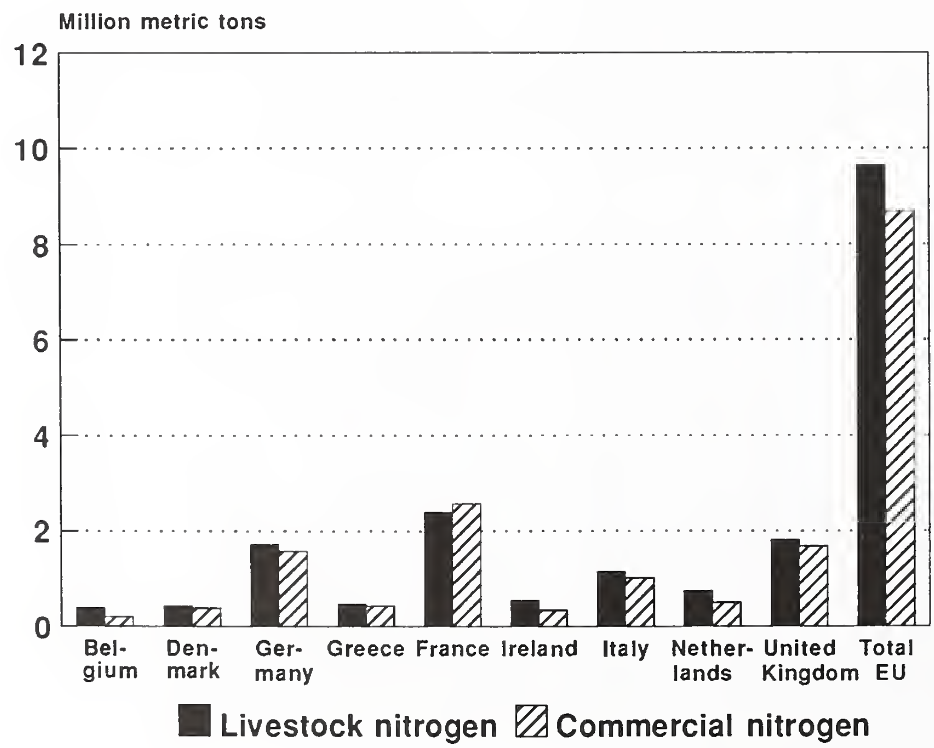
Table 5--Nitrogen produced from livestock manure, EU, 1986[1]

Country	Dairy	Beef	Pigs	Layers	Broilers	Sheep	Total
			1,000 metric tons				
Belgium/ Luxembourg	65	137	122	5	41	10	380
Denmark	58	109	224	2	40	1	434
Germany	349	651	549	25	102	42	1,718
Greece	14	36	33	8	32	332	455
France	416	1,043	275	33	299	327	2,393
Ireland	98	272	30	2	15	120	537
Italy	197	380	154	23	138	265	1,157
The Netherlands	149	176	249	19	143	16	752
United Kingdom	208	604	217	25	254	511	1,819
Total	1,554	3,408	1,853	142	1,064	1,624	9,645

[1]Livestock numbers from *Agricultural Situation in the Community* (Commission of the European Communities, selected issues), are multiplied by the coefficients in table 4. Beginning inventories are used for cattle; number slaughtered are used for pigs and sheep, with 7 percent and 50 percent being added to account for breeding animals; and the number of eggs hatched for chick placement for eggs and meat are used for layers and broilers.

Figure 4

Total nitrogen from livestock manure and commercial fertilizer



nitrogen levels. Reductions in livestock numbers may achieve this purpose, and are a standard by which to judge the need for additional policy mechanisms to meet residual nitrogen objectives. The ultimate choice in policies will reflect, at least partly, a political balance between different interests, and is beyond the scope of this study. Because the Nitrate Directive only has a provision for reducing livestock manure, this study assumes, in the Nitrate Directive scenario, that the lower residual nitrate comes mostly from reduced livestock production and manure application.

Possible reductions in livestock production that are necessary to reduce residual nitrogen levels to the MAR are calculated assuming that manure nitrogen and livestock production are proportional. Achieving the reduction in residual nitrogen suggested in table 6 would therefore require large reductions in livestock production for Belgium, Denmark, and The Netherlands (table 7, column 1). These reductions may be politically difficult to achieve, however, and imply the need for coincident reductions in fertilizer use, manure management schemes, and other policies to reduce residual nitrogen levels. The present study addresses only the need to reduce fertilizer use.

The intent of the Nitrate Directive that livestock manure be considered the main source of the nitrate problem will likely guide policies to reduce both livestock production and fertilizer use. Therefore, livestock production would probably be reduced by a greater percentage than fertilizer use under such a policy. A number of formulas could achieve this purpose, because the relative proportions are likely to be politically influenced.

One formula that would meet the intent of the Directive could be based on the idea that the level of residual nitrogen is a measure of the nitrate problem, and the share of livestock nitrogen in that residual represents the contribution of livestock to the problem. Using this reasoning, livestock production should be reduced in proportion to its share of that residual, with any remainder of the reduction in the residual necessary to meet the MAR being from fertilizer. For example, in Belgium, manure nitrogen of 380,000 tons (table 5) exceeds the total nitrogen residual of 369,000 tons (table 6). The 107,000-ton decline in residual nitrogen necessary for Belgium to meet the MAR could be achieved exclusively with a 28-percent reduction in livestock nitrogen (table 7).

Manure nitrogen comprises 82 percent and 77 percent of the nitrogen residual in Denmark and The Netherlands. For Denmark, 82 percent of the 48,000-ton reduction in the nitrogen residual would be from

Table 6--Nitrogen applied, uptake, and residual, EU, 1986

Country	Total nitrogen: Applied	Total nitrogen: Uptake	Residual nitrogen: Total	Residual nitrogen: Per ha	Reduction needed to achieve MAR	
	- - - 1,000 metric tons	- - -		kg	1,000 tons	Percent
Belgium/Luxembourg	580	211	369	240	107	29
Denmark	816	287	529	187	48	9
Germany	3,295	1,314	1,981	165	0	0
Greece	887	403	484	84	0	0
France	4,961	2,406	2,555	81	0	0
Ireland	879	407	473	83	0	0
Italy	2,167	1,027	1,140	65	0	0
The Netherlands	1,255	285	972	480	632	65
United Kingdom	3,490	1,522	1,969	106	0	0
Total	18,333	7,862	10,473	108	787	8

Table 7--Reductions in livestock and fertilizer use to achieve the MAR, 1986

Country	Source of reductions to achieve MAR: Livestock	Livestock and fertilizer: Livestock	Livestock and fertilizer: Fertilizer
		Percent	
Belgium/Luxemborg	28	28	0.0
Denmark	11	9	2.2
The Netherlands	84	65	28.0

livestock nitrogen, and represent 39,360 tons, or 9 percent (table 7), of total livestock nitrogen. The remainder of the residual would then be achieved with a 2.2-percent decrease in fertilizer use. Similarly, residual nitrogen would be reduced to the MAR for The Netherlands with decreases in livestock production and fertilizer use of 65 percent and 28 percent (table 7).

In theory, at least, fertilizer use in Belgium, Denmark, and The Netherlands could be reduced significantly without reducing crop yields, because manure could replace fertilizer as the nitrogen source. Veenendaal and Brouwer (1991) suggest that significant reductions in fertilizer use in The Netherlands could be made without affecting yields. Furthermore, actual application rates that are close to the maximum amounts recommended for Denmark and The Netherlands may indicate some inefficiency in use (Leuck, 1993). The assumption of no yield reduction in this study provides a benchmark against which to evaluate the Nitrate Directive.

A fertilizer tax, on the other hand, will have effects on grain production that are not limited to the above three countries, but that occur in regions of the EU where fertilizer may be a limiting input. Therefore, the fertilizer tax is allowed to have some yield effect.

The effects of the Nitrate Directive are incorporated into a trade-modeling framework so that its effects on EU agricultural production and world trade can be better understood. The world model includes the EU as an aggregate unit. Therefore, EU-wide reductions in livestock production are calculated as weighted averages of the reductions in each of the three countries.

The EU-wide reductions in livestock numbers are moderate (table 8). Pig production is reduced the most, followed by reductions in egg and broiler numbers. Dairy and beef numbers are reduced moderately, but sheep numbers are reduced by less than 1 percent.

These aggregate reductions represent the decreases in livestock production that are exogenously entered into a trade model summarized in the next section. First, however, we present a review of previous models that have linked nitrogen levels to agricultural production. This review suggests some of the tradeoffs among data, geographic and commodity details, and the policies that such a model might accommodate.

Environmental and Agricultural Policy Models

Only a few models depict the effects of EU environmental policies on nutrient levels or agricultural trade. Each has a different structure or policy focus that depends on the objectives of the researchers and their available time and data. Only the first three of the models summarized below have a nutrient balance component, which is necessary for measuring residual nitrogen levels. Among the environmental scenarios, only the first study looks at policies that directly affect manure or livestock production. The others analyze various policies to reduce commercial fertilizer.

Koopmans (1987) adds a nutrient balance component to the Basic Linked System (BLS), a general equilibrium model of the EU at the International Institute for Applied Systems Analysis (I.I.A.S.A, 1986). The contribution of both livestock and commercial fertilizers is included in the nutrient balance that measures the application of six potential pollutants to the soil and their uptake by crops. However, no estimates are made of the effects that volatilization, acidic deposition, or other elements in the nitrogen cycle may have on residual nitrogen. The study contains a set of coefficients that measure the amount of these six pollutants in the manure of cattle, pigs, poultry, horses, and sheep, the uptake by grass (aggregate category of grains), and the amounts stored in straw.

A base simulation predicts a 5-percent increase in the amount of residual pollutants between 1980 and the year 2000, with nitrogen increasing 14 percent. The combination of a 50-percent tax on fertilizer and a 20-percent reduction of cultivable land area reduces the residual level of nitrogen by nearly 30 percent. This is achieved with a decline of only 12 percent in the use of fertilizer and a small increase in the application of livestock manure and uptake by crops. Agricultural self-sufficiency is reduced by only 4 percent, because livestock production increases, although production of wheat, coarse grains, and rice decreases by 33 percent, 20 percent, and 60 percent.

Veenendaal and Brouwer (1991) analyze policies to reduce nitrogen pollution in The Netherlands with a mathematical programming model that maximizes net farm revenues. They represent the nitrogen cycle in much greater detail than Koopmans. First, they identify three regions and take account of regional variations in pollution levels as influenced by soil type and weather conditions. They also include relationships that measure the inflow of nitrogen from

imported feedstuffs and acid rain, and the outflow through volatilization, crop harvests, and animal slaughter. The processing and transport of livestock manure for use as fertilizers is also modeled.

This model analyzes the role of various measures to reduce levels of environmental pollutants below those from a base run covering 1985 to 2010. The input of nitrogen is reduced 40 percent below the base level in 2010, and is accomplished by reducing nitrogen from commercial fertilizer by 75 percent and agricultural net income by 24 percent. The processing and transport of manure to substitute as fertilizer, reductions in livestock density, and restrictions on the application of manure play the dominant roles in reducing nitrogen. However, policies to reduce the nitrogen content of livestock feeds and improve the application of nitrogen to fields may be the more cost-effective measures.

Becker (1993) analyzes the effect of reducing by 50 percent commercial nitrogen use on agricultural production, input demand, and farm income in 10 regions of Germany. His model uses duality theory to incorporate inputs, including livestock manure, into a programming model that maximizes income. However, incomplete time series data do not allow the estimation of all own- and cross-price elasticities from a multi-equation system, as is theoretically proper. Rather, the elasticities are generated from single-equation models, restrictions inferred from theory, and expert opinion.

Becker's results suggest that a 50-percent reduction in commercial nitrogen would allow "sustainable development," meaning implicitly that nitrate may cease to accumulate in water supplies. This is a more restrictive scenario than the Nitrate Directive implied and requires a 100-percent tax on fertilizer. Manure nitrogen is allowed to substitute up to 40 percent for commercial nitrogen. Crop supplies decrease between 13 percent and 19 percent, and net income decreases by nearly 3 percent for Germany.

Garcia and Randall (1991) simulate the effects of measures to reduce fertilizer by incorporating capital, energy, and fertilizer into the ST86 version of SWOPSIM (Roningen, 1986). They first econometrically estimate key parameters relating to the substitutability of these inputs using a translog function. A derived marginal cost function is used to calculate the elasticity of output supply with respect to the price of fertilizer. This exercise was undertaken for wheat in the United States, France, and the United Kingdom, and for corn in the United States and France.

They then calculate the effects of a 25-percent fertilizer tax on output, assuming perfectly elastic fertilizer supply, as: U.S. wheat: -5.4, U.S. corn: -9.9, French wheat: -11.7, French corn: -11.1, and U.K. wheat: -7.8. The trade effects of fertilizer-tax scenarios are simulated in a 12-commodity SWOPSIM model that disaggregates the 12 EU countries by applying these percent changes in output as supply shifters. The most significant trade effects occur if all three countries impose the 25-percent fertilizer tax. In that case, the world corn price increases by 17 percent and the world wheat price increases by 7 percent. At the new world prices, U.S. production of corn is down 6 percent and wheat is down 7 percent because of cross-commodity price effects.

Hartmann (1994) uses the 1989 version of SWOPSIM to simulate unilateral and bilateral quotas on commercial nitrogen ranging from 25 percent to 95 percent for the United States and the EU. Implied tax rates on nitrogen are not calculated. Hartmann divides inputs into five categories: nitrogen, other fertilizer, pesticides, arable land, and pasture land. Own- and cross-price elasticities for these inputs are from a variety of sources.

Hartmann's simulation of a 25-percent nitrogen quota in the EU reduces crop production by between 6.1 percent and 7.6 percent, and decreases livestock production by between 0.1 percent and 1.4 percent. World prices increase by 3.5 percent to 6.8 percent for grain and 0.8 percent to 1.3 percent for livestock products. With a 50-percent decline in nitrogen in both the United States and the EU, world price increases are slightly more than double these values.

Abler and Shortle (1992) develop a simulation model of the United States, the EU, and the rest of the world to assess the impact of agricultural policy reform and

Table 8--Reductions in EU livestock numbers to achieve the MAR

Item	Dairy	Beef	Pigs	Layers	Broilers	Sheep
				Percent		
Total EU	7.8	4.8	11.7	10.1	10.1	0.91

environmental policies. The model has four commodities: wheat, corn, coarse grains, and soybeans. Production is modeled with nested constant elasticity-of-substitution functions. Inputs consist of capital, labor, land, and chemicals, including fertilizers, insecticides, fungicides, and herbicides. Land is assumed to be commodity-specific, and constant-elasticity functions relate the supply of each land type to its own and other prices. Other input supply functions are perfectly elastic.

The environmental policy simulated by Abler and Shortle is a quota that reduces the use of chemicals by 10 percent for all crops. In the case of such a unilateral policy for the EU, grain supplies decline by 5 percent to 7 percent in the EU in both the medium and long run. World prices increase by only 1 percent and 2 percent for wheat and coarse grains in the long run, and do not change for corn and soybeans. World prices rise by 3 percent to 10 percent in the medium run. The implied tax rates necessary to reduce chemical use by 10 percent range from 60 percent to 70 percent in the medium run, but only 5 percent to 10 percent in the long run.

To introduce a fertilizer tax into ST86, Gunasekera and others (1992) adjust the producer subsidy wedge by calculating the output-tax equivalent of a fertilizer tax. They conclude that even a 75-percent tax on nitrogen fertilizer would only reduce output of grains and oilseeds between 0.4 percent and 1.8 percent, but that CAP reform may meet both trade and environmental objectives. The method of introducing a fertilizer tax does not allow it to influence other variables in the model by reducing fertilizer usage along a demand function.

Hertel, Peterson, and Stout (forthcoming) use SWOPSIM's data set and elasticity parameters as the building blocks in a general equilibrium international trade model. Agriculture is treated as a multiproduct industry, and SWOPSIM own-price elasticities of supply are incorporated into the model through the use of a revenue function. The revenue functions for each region are calibrated to replicate the vector of SWOPSIM own-price compensated elasticities of supply for the base data. Resources were held fixed among sectors in one scenario and allowed to shift between sectors in a second scenario, as determined by an elasticity of resource transformation.

Hertel, Peterson, and Stout analyze the impact of a 100-percent tax on nitrogen fertilizer by converting it to its output equivalent. The tax has a modest impact on EU agriculture. The output of wheat, for example, drops 2.7 percent with no mobility and 3.6 percent with resource mobility. Trade responds more, in percentage terms. Wheat exports from the EU fall by 9.8 percent with no mobility and 13.9 percent with mobility, while corn imports into the EU increase by 22 percent and 34 percent. World prices increase by no more than 1.2 percent. In the United States, production of wheat, corn, and other coarse grains increases by 0.7 percent, 0.4 percent, and 1.2 percent.

Most of the above studies have also looked at the environmental effects of reforming the CAP by lowering EU price supports to varying degrees. These results generally support the view that reduced EU price supports will positively affect the environment by reducing agricultural production.

One of the key variables that relate policy changes to effects on the environment is the demand for fertilizer, and the above studies approach the demand for fertilizer in varying ways. Those studies that attempt to estimate input demand using duality theory appear to have greater input and output response to fertilizer taxes (Garcia and Randall, 1991; Becker, 1993; and Hartmann, 1994). However, these estimates are not indepth analyses of the role of fertilizer demand in agriculture. The other studies rely in one way or another on Burrell's (1989) work on the European fertilizer market.

The Demand for Fertilizer

Most attempts at estimating the parameters needed to analyze environmental policies have focused on the own-price elasticity of fertilizer. Burrell (1989) reviews the theoretical framework underlying this parameter, and both econometric and mathematical programming methods of estimating it. In single-equation econometric models, demand is regressed on prices and demand-shift variables. These models are based only loosely on production theory, and the estimates are interpreted as Marshallian (uncompensated) elasticities. Since each model is specified differently, the elasticities cannot be meaningfully compared. The range of estimates are in table 9.

In the systems approach, the model equations are derived via duality theory from some production technology. When a cost function is used, the input demand functions give estimates of Hicksian (compensated) elasticities; when a profit function is used, the estimates are of Marshallian input demand elasticities. The systems approach used the restrictions that neoclassical production theory imply. Unfortunately, many of these restrictions fail to hold when confronted with the data. Because the underlying

theoretical assumptions appear to be invalid, the results of these models are difficult to evaluate.

In the linear programming (LP) models, elasticities are estimated from the change in optimum fertilizer use resulting from price changes. However, the large variation of response across farms may invalidate identification of "typical" response functions. Secondly, uncertainty surrounding the uptake of nitrogen may lead risk-averse farmers to apply more than model solutions indicate. LP studies also often limit the response of farms, in particular to switch among crops. Finally, neither the econometric nor the LP models deal adequately with technical change, suggesting that such estimates measure shortrun effects.

The ST86 Trade Policy Model

The above review points out three attributes of a multi-commodity model that are necessary to address the global trade implications of unilateral EU environmental policies. First, a nitrogen balance component is necessary to ascertain the contribution of different commodities to residual nitrogen. A fertilizer sector that has a plausible link to both crop yields and fertilizer supply is a related need. The third essential characteristic is multiple world-trading regions that allow tracing of trade and world price effects.

The last attribute is contained in ST86, which has been widely used to analyze agricultural policies and was modified by Garcia and Randall (1991), Gunasekera and others (1992), and Hartmann (1994) to analyze the effects of a nitrogen tax. ST86 is a static, partial equilibrium model of world agricultural trade (Roningen and Dixit, 1989) constructed in the SWOPSIM framework (Roningen, 1986), using the ST86 database (Sullivan and others, 1989). ST86 is easily modified to analyze environmental policies by adding a nitrogen balance component and a nitrogen fertilizer sector.

The nitrogen fertilizer sector is incorporated into ST86 in a way similar to the feedgrain demand. The quantity of crops using fertilizer enters into the fertilizer demand equation and is exponentially weighted by its proportion of total nitrogen fertilizer use. The share coefficients are calculated from the SPEL Group data (1989).

There has not been much modeling of fertilizer supply, in the context of placing restrictions on the use of fertilizers, except by McCorriston and Sheldon (1989). Their study stressed an imperfectly competitive market structure for the fertilizer sector. In this study, an infinite supply elasticity is used, and a competitive market structure for the fertilizer supply industry is assumed.

As in the feedgrain specification, the share data, along with other model parameters, can be used to calculate a fertilizer cross-price elasticity for each of the crops that use fertilizer. This relationship is based on the symmetry restriction of production functions implied by neoclassical microeconomic production theory. The explicit SWOPSIM equation used to calculate the elasticity is:

$$(TFE/CPV)*OPSE \qquad (1)$$

where TFE is the total fertilizer expenditure, CPV is the value of crop production, and OPSE is the own-price supply elasticity.

Several other attributes are also desirable in the policy model. However, the cost of adding these attributes to SWOPSIM must be balanced against their marginal benefits. The current policy concerns are not intersectoral, thus adding a nonagricultural sector appears unnecessary at this preliminary stage. It is also quite costly to pursue a subregional analysis of nitrogen levels, as was done by Veenendaal and Brouwer (1991).

Considerable interest in shifts may occur among inputs in response to policy changes. Therefore, other inputs (besides fertilizer) are added to the model using the so-called joint-products approach, based on duality theory. This approach is still under development, but imposes a more rigorous theoretical relationship between inputs and outputs than exists in the basic

Table 9--Range of fertilizer demand elasticity estimates in models surveyed by Burrell

Type of model	Type of elasticity		
	Hicksian	Marshallian	Augmented Hicksian
Single-equation econometric	NA	-0.19 to -1.18	NA
Econometric system	-0.49 to -1.2	-.19 to -2.2	NA
Linear programming	NA	NA	-.08 to -.04

NA = Not applicable.
Source: Burrell (1989).

ST86 model. Analysis of the three policies with the joint-products approach is discussed in the Appendix.

The Effects of Policy Alternatives on Production, Nitrogen Balance, Trade, and World Prices

The three policies that are analyzed are modeled as unilateral EU policy changes, that is, no other country is assumed to change its agricultural policies either in conjunction with or as a result of the EU changes. These policies are: (1) the Nitrate Directive, (2) a hypothetical 50-percent fertilizer tax, and (3) CAP reform. The Nitrate Directive and CAP reform are also combined because they are to be implemented together. The method is comparative static for the base year 1986.

Two modeling details are worth mentioning. The first is how the amount of EU acreage set-aside is calculated. The EU set-aside program does not cover specific crops, as do U.S. commodity programs. However, in consultation with European experts and using unpublished survey data, the Europe Branch of the Economic Research Service estimates that individual commodity land area reductions would likely be as follows: wheat: -7 percent; corn: -9 percent; other coarse grains, soybeans, and oilseeds: -12 percent.

Another important modeling detail is that the price transmission elasticities from ST86 are kept fixed at preliberalized levels. These elasticities measure the degree to which the EU insulates itself from world-price disturbances. These elasticities are quite small, implying that EU policy changes will have magnified effects on world prices, because the EU and other protectionist countries will not absorb the associated world price shocks.

An unresolved question in CAP reform is what effects the direct payments meant to compensate producers for support price reductions will have on production. In terms of U.S. policy discussions, the issue is the degree to which the direct payments are decoupled from production decisions. Full decoupling is assumed in this study, while Haley (1993) analyzes the effects of relaxing this assumption.

The Effects on Production

The two environmental policies have different effects on EU agriculture. The Nitrate Directive affects only livestock production, while the fertilizer tax only affects crop production (fig. 5). The effects of the Nitrate Directive on livestock are larger, however, than the effects of the fertilizer tax on crops. Livestock production decreases by the amounts specified in the Directive, 5 percent for beef and about 8 to 12 percent for other livestock products. The 50-percent tax on nitrogen fertilizer reduces crop production by no more than 2 percent.

The influence of these policies on different sectors occurs because ST86 does not allow substitution between the supply of crops and livestock. Most of the livestock produced in the EU is in intensive production units, and is therefore not very land intensive, or is restrained from expanding by the milk quota, as is dairy, and beef to some extent. Therefore, low or zero cross-price elasticities of supply between crops and livestock are not unreasonable. The effects of relaxing this assumption are analyzed in the joint products approach discussed in the Appendix.

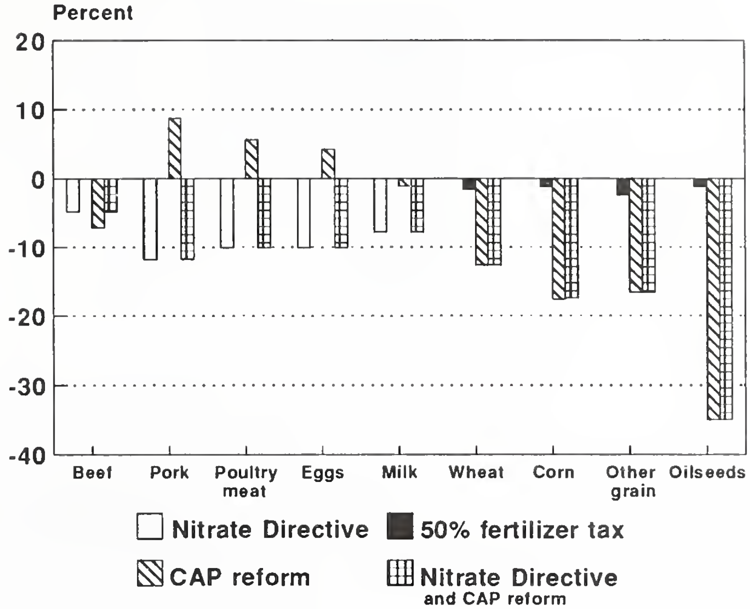
Other assumptions regarding a fertilizer tax lead to only slightly larger decreases in production. A 75-percent fertilizer tax leads to incremental decreases of about 0.5 percent in production. Changing the elasticity of fertilizer supply from perfectly elastic to 0.5 also leads to incremental decreases of about 0.5 percent in production. These levels of fertilizer taxes do not yield production responses as large as may occur under CAP reform.

The effects of CAP reform on supply are more varied and significant than the effects of the environmental policies. Commodities for which price reductions under CAP reform are greater tend to decrease production the most. These commodities include grain and oilseeds. Oilseed production decreases about 38 percent. Corn and other coarse grains (mainly barley) production decreases about 18 percent. Wheat production decreases about 13 percent.

Under CAP reform, the livestock product-to-feed price ratio is increased because livestock prices decrease less than grain and oilseed prices. However, this ratio increases the least for beef, allowing substitution to occur away from beef production. Beef production decreases about 7 percent, and is the only livestock with decreased production under CAP reform. Pork production increases about 8 percent, and the supply of poultry products increases by about 5 percent. Dairy production does not increase, because it is bound by the milk quota.

Under the combination of the Nitrate Directive and CAP reform, livestock production decreases by the amounts implied by the Nitrate Directive, while crop production decreases by the amounts implied by CAP

Figure 5
EU supply changes under selected policy options



reform. This asymmetry of response occurs, in part, because the increase in the livestock product-to-feed price ratio under CAP reform keeps livestock production bound against the constraint implied by the Nitrate Directive. Furthermore, the Nitrate Directive has no independent effect on crop production, leaving it to decline in response to CAP reform.

The implication of this scenario is that the amount of residual nitrogen decreases by a greater amount than in the case of the Nitrate Directive alone. Thus, it seems possible to substitute the reduction in residual nitrogen from reduced cropping for the increased residual from increased livestock production. However, the reductions in livestock production calculated above as implied by the Nitrate Directive are located in Denmark, Belgium, and The Netherlands. Because most grain is produced elsewhere in the EU, most of the reduction in residual nitrogen ST86 indicated for CAP reform would not occur in these three countries.

The addition of a 50-percent fertilizer tax to CAP reform is not discussed, because its effects are not significant.

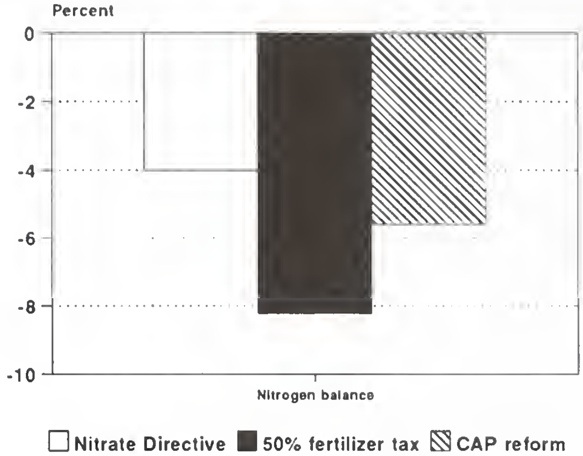
The Effects on Nitrogen Balance

The Nitrate Directive and CAP reform reduce the total residual nitrogen about 4 percent and 5 percent (fig. 6). In the case of the Nitrate Directive, residual nitrogen levels decline because of reduced livestock numbers. Under CAP reform, the decline in residual nitrogen levels occurs because of reduced crop production, and is offset somewhat by increases in all livestock except beef. However, this decline is spread throughout the EU, while the problem of nitrate pollution is centered in Belgium, Denmark, and The Netherlands. Therefore, the model results overstated the contribution of CAP reform toward reducing residual nitrogen in these polluted areas.

The 50-percent nitrogen tax reduces residual nitrogen by about twice the amount targeted by the Nitrate Directive. This is a rather significant reduction in residual nitrogen levels. At the high levels of nitrogen used, the response of crop production to fertilizer use at the margin is quite small. Nitrogen fertilizer use declines about 10 percent in response to the tax, and grain production decreases about 2 percent.

The effects of the fertilizer tax are similar to the effects of CAP reform, in that they are spread throughout the EU. Unlike CAP reform, however, there are no offsetting increases in livestock numbers under the fertilizer tax. Therefore, the tax would lead to greater reductions of residual nitrogen levels in Belgium, Denmark, and The Netherlands, because, under this scenario, livestock is unaffected in these regions. Nevertheless, it is unclear in this aggregate analysis whether residual nitrogen levels would decline as much with the fertilizer tax in these countries as it does under the Nitrate Directive. Furthermore, a tax would decrease nitrogen use in grain-producing regions of the EU where nitrate problems do not exist.

Figure 6
Changes in nutrient balance due to selected policies



The Effects on Net Trade and World Prices

The changes in net trade and world prices tend to reflect the shifts in EU production that occur under each scenario. These effects are significant for most commodities in all scenarios except the fertilizer tax. The fertilizer tax reduces grain exports by very small levels, because EU grain production is not especially sensitive to the tax. Some changes in consumption occur in the CAP reform scenario because livestock product prices decrease. Beef and dairy prices in the EU decrease about 15 percent and 3 percent (see page 8), while other livestock product prices reflect the relatively small changes in world prices that occur under CAP reform (fig. 9).

Net Trade Effects for the European Union

The Nitrate Directive reduces the net exports of all livestock products because their production is reduced (fig. 7). While the changes in livestock supply are relatively small in this scenario, the changes in net trade are rather large, because trade is a relatively small percentage of production. The EU shifts from being a net exporter to a net importer of all livestock products except beef, the net exports of which decline about 50 percent.

Under CAP reform, the net exports of all livestock products increase, except beef, whose production decreases, and dairy products, for which production is bound by the milk quota. The same amount of milk is used to produce slightly more cheese exports and to produce an offsetting decline in butter and milk powder exports. The supply of all other livestock products increases under CAP reform. The EU shifts from being a net exporter of beef to being a net importer because of the combination of decreased beef supply and increased beef demand, resulting from the relative decline in the EU price of beef. Increased demand for other livestock products does not significantly affect trade.

Under the combination of CAP reform and the Nitrate Directive, the net exports of all livestock products are reduced, because livestock supplies are reduced by the amounts implied by the Nitrate Directive instead of being allowed to react to the prices under CAP reform. The EU becomes a net importer of beef because consumer demand increases significantly, as compared with its continued position as a net exporter in the Nitrate Directive scenario. However, net imports are less under the combined CAP reform and Nitrate Directive than under CAP reform alone, because the supply of beef does not decline as much under the combination as it does under CAP reform alone. Net trade for the other livestock products is similar in magnitude under the combination to what it is under the Nitrate Directive alone, with the difference for pork and poultry representing a small decrease in demand and the difference for eggs reflecting a small increase in demand.

The changes in the net trade of grains and oilseeds occur because less are fed under the Nitrate Directive, and because more are fed and less are produced under CAP reform (fig. 8). Under the Nitrate Directive, feed demand decreases against unchanged production. The net exports of wheat and other coarse grains increase about 10 percent and 50 percent; the net imports of corn drop by 100 percent; and the imports of oilseeds (in 44-percent soybean meal equivalents) fall nearly 20 percent. Under CAP reform, the net exports of wheat decrease about 80 percent, and the net imports of corn and oilseed meal increase by about

Figure 7
Net trade effects for EU livestock, selected policies

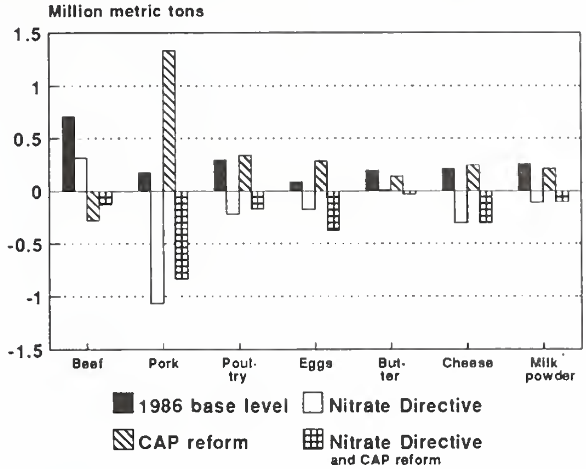
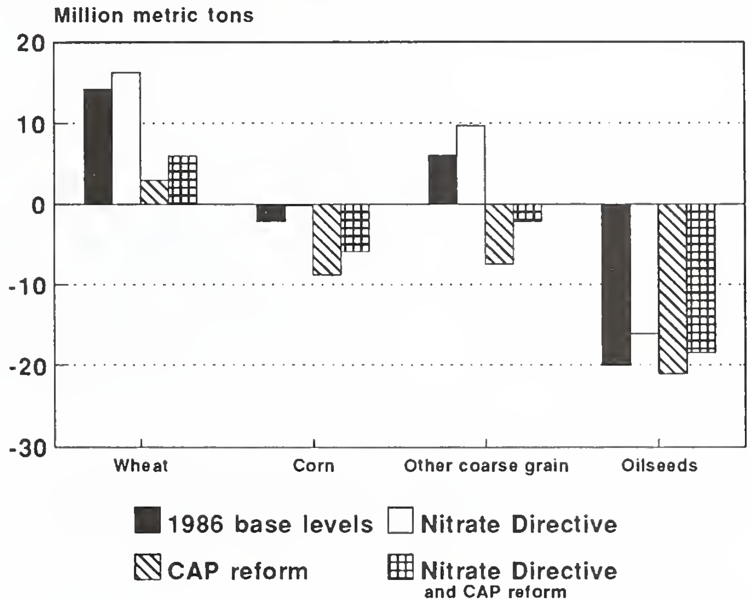


Figure 8
Net trade effects for EU grain, selected policies



300 percent and about 5 percent. The EU shifts from exporting 5 million tons of other coarse grains to importing about 8 million tons.

The net trade effects arising from the combination of the Nitrate Directive and CAP reform are the result of decreases in both crop supply and feed demand resulting from lower livestock production. For grains, the decrease in crop supply exceeds the decrease in feed demand. Therefore, net exports of wheat and coarse grains decrease and net imports of corn increase. The EU again becomes a net importer of coarse grains under the combination of the two policies, but not by as much as under CAP reform alone. For oilseed meal, net imports decrease slightly, because the decrease in oilseed supply is less than the decrease in feed demand.

Imposing the Nitrate Directive alone has less effects on net trade than adding the Nitrate Directive to the CAP reform scenario, although the effects run in the same direction. Livestock feed demand increases over the base level under CAP reform, but is reduced from that same level when the Nitrate Directive is added. Therefore, the total reduction in livestock feed demand is greater when the Nitrate Directive is added to CAP reform than when only the Directive is imposed on the base level.

World Price Effects

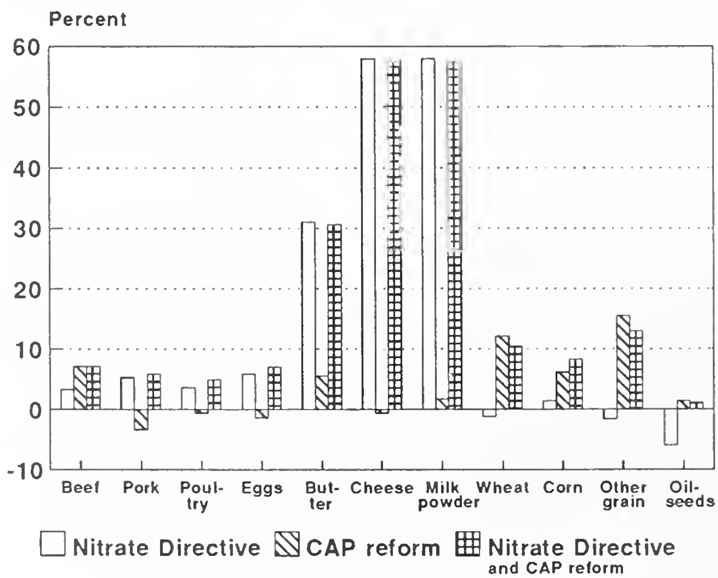
World prices generally increase under all scenarios for most products. CAP reform tends to increase grain and oilseed prices the most, because EU grain production decreases. Livestock prices fall under CAP reform because EU livestock supplies increase. The exceptions are beef prices, which increase slightly because beef supplies decline, and dairy products, whose price changes reflect the slightly larger amount of cheese and slightly smaller amounts of butter and milk powder that are exported from a constant amount of milk bound by the milk quota. All livestock prices, except beef, increase about the same amount in both the Nitrate Directive alone and the combination of the Directive with CAP reform, because all livestock numbers are reduced by the same amounts in both scenarios. Beef prices increase more when CAP reform is added, because consumer demand increases in the EU. The small differences are due to shifts in consumer demand due to CAP reform (fig. 9). World beef prices increase the most under CAP reform, because beef supply decreases the most in that scenario.

As a result of the trade effects under the Nitrate Directive, world prices increase for all livestock products and decrease for all crops except corn. Livestock production and feed demand decline in the EU under the Nitrate Directive. The largest increases are nearly 60 percent for cheese and skim milk powder. These large increases occur because the EU supplied about half of world exports of butter and cheese and one-fourth of world milk powder exports in 1986 (Commission of the European Communities, *Agricultural Situation in the Community*, 1987), making the changes in EU exports a major factor in world trade in this scenario. Oilseed prices drop about 5 percent, but the change in grain prices is small. The EU is the major importer of oilseeds and meal, but a relatively smaller player on world grain markets.

Under CAP reform, world prices rise for beef and all dairy products except cheese, because their supply decreases in the EU. World prices fall for pork and poultry products, because their supply increases. World prices for grain and oilseeds rise, because their production declines. Price increases range from about 2 percent for powdered milk to about 8 percent for beef, but exceed 10 percent and 15 percent for wheat and other coarse grain, and are about 8 percent for corn. Oilseed prices only increase about 1 percent despite the 35-percent drop in EU oilseed production. EU production represents a very small percentage of world oilseed production. This is also reflected in the very small increase in net imports of oilseed meal (fig. 8).

World prices for all products increase under the combination of the Nitrate Directive and CAP reform. Prices increase about the same amount for beef and crops as they do under CAP reform alone, because EU supplies and demand are similar. For pork and poultry products, prices increase about as much as under the Nitrate Directive, because market conditions in the EU are similar for these products under both scenarios. Prices increase the most for dairy products

Figure 9
World price effects, selected policies



(30 to 60 percent). Price increases for dairy products under the combination of the Directive and CAP reform are similar to price increases under the Nitrate Directive alone, because dairy production drops by the same amount under both scenarios, but EU demand does not increase significantly when CAP reform is added. Under the combined scenario, oilseed prices increase slightly less than under CAP reform alone, because slightly less oilseeds are imported to satisfy reduced feed demand.

Net Trade for the United States

Net trade of products for which the United States is a net exporter generally increases, and net trade of products for which the United States is a net importer generally decreases under all scenarios (figs. 10-11). The Nitrate Directive has the most favorable implications for the net imports of livestock products and the least favorable implications for grains and oilseeds, because both EU livestock and feed demand decline under the Directive. CAP reform has more favorable implications for U.S. trade in grain and oilseeds and less favorable implications for trade in livestock products, because EU grain production declines and EU livestock production tends to increase in this scenario.

Under the Nitrate Directive, net imports for the United States decline for beef and increase for pork. Net exports increase for poultry products, but do not change for the other products. Beef and pork are the only commodities in this study for which the United States is a net importer. Under the Nitrate Directive, net imports of beef decline about 75 percent, and net imports of pork increase about 10 percent.

Figure 10

Net trade effects for U.S. livestock, selected policies

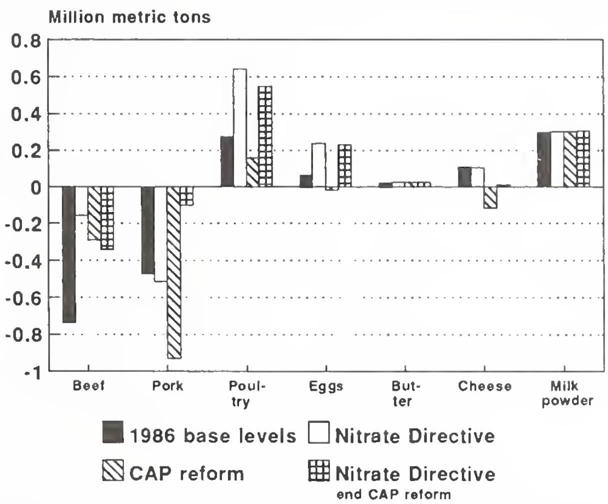
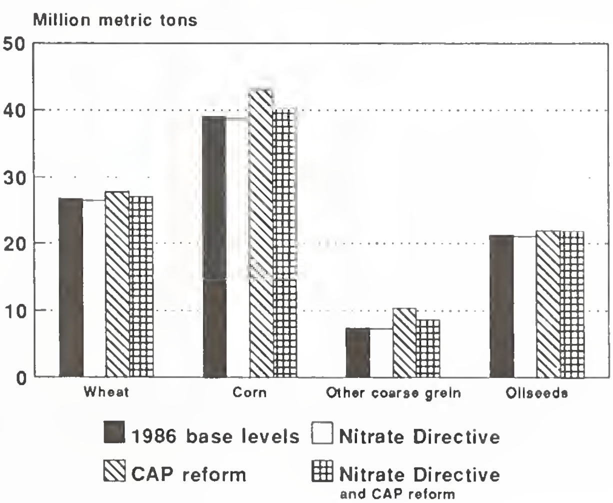


Figure 11

Net trade effects for U.S. grain, selected policies



CAP reform affects net trade in livestock products for the United States differently than does the Nitrate Directive. Net beef imports under CAP reform decline by 50 percent, which is lower than the decline under the Nitrate Directive. Net imports of pork increase more under CAP reform than under the Nitrate Directive, or double in magnitude from the 1986 base level. Under CAP reform, exports of poultry meat decline, and the United States shifts from being a net exporter of eggs and cheese to a net importer. Other dairy products are not affected. The net exports of all grains and oilseeds increase more under CAP reform than under the Nitrate Directive.

The addition of the Nitrate Directive to CAP reform slightly increases the level of U.S. beef imports and reduces pork imports by about 90 percent. In the combined scenario, exports of poultry products increase, but dairy product exports do not change much. Net exports of corn and other coarse grains decrease slightly, but remain above the base level. Wheat and oilseed exports decrease slightly but also remain above the base level.

Self-sufficiency

The Nitrate Directive may significantly affect the member countries' self-sufficiency in livestock consumption (table 10). The effects are especially significant for Belgium and The Netherlands, where livestock numbers may decline rather significantly under the Directive. Belgium becomes less than 100 percent self-sufficient in butter and poultry products, while The Netherlands becomes less than self-sufficient in beef and veal, butter, pork, and poultry meat.

At the total EU level, self-sufficiency drops below 100 percent for pork and poultry products, and to 100 percent for cheese. The declines in self-sufficiency for the total EU nevertheless imply that beef exports decline by 50 percent, and dairy product exports decline between 34 percent and 100 percent. For pork and poultry products, the EU would become a net importer.

Conclusions and Limitations

In the EU, residual nitrogen levels are most reduced with a fertilizer tax. However, this reduction is spread over cropland and may not sufficiently reduce nitrate pollution where needed, in regions of intensive livestock production. CAP reform is a less successful means of reducing residual nitrogen levels in intensive livestock areas, because pork and poultry production increase and dairy production remains stable. Only a targeted policy, such as the Nitrate Directive, reduces nitrate pollution to desired levels where needed. Significant reductions in livestock numbers will be necessary in Denmark, Belgium, and The Netherlands.

The Nitrate Directive implies possible reductions in EU livestock production ranging from 1 percent for sheep to 12 percent for pigs. Reductions would likely be highly concentrated in Belgium, Denmark, and The Netherlands, but are subject to many factors that are unknown or difficult to account for. Smaller reductions are likely, to the extent that manure is more carefully stored, handled, and applied, or more easily substitutes for commercial fertilizer. Livestock may also be fed differently or production may shift to

Table 10--Self-sufficiency: 1991 averages and estimated levels under the Nitrate Directive

Country	Beef and veal	Butter	Cheese	Milk[2]	Pork	Poultry meat	Eggs
				Percent			
Belgium/Luxembourg:							
1991-92	149	124	35	182	176	115	126
Estimated	107	89	25	131	127	83	91
Denmark:							
1991-92	197	188	368	120	373	216	103
Estimated	179	171	335	109	339	197	94
The Netherlands:							
1991-92	194	174	294	27	257	205	339
Estimated	68	61	103	9	90	72	119
Total EU:							
1991-92	110	111	109	132	105	108	102
Estimated	105	102	100	121	93	97	92

[1]The self-sufficiency percentages for 1991-92 are from Commission of the European Communities, *Agricultural Situation in the Community*, selected issues. The estimated percentages are calculated by the authors from the output of the ST86 simulation model.
[2]Dried skim milk powder.

other countries where problems do not exist or are not as severe. A system of taxes and/or subsidies may be necessary to reduce residual nitrogen levels.

Aggregate measures of residual nitrogen do not reveal excessive amounts of residual nitrogen in some regions where nitrate problems are known to exist, such as certain parts of the United Kingdom, France, Germany, and northern Italy. Therefore, some reduction in livestock numbers may be required in these countries, except to the extent that production shifts to other regions because of policy inducements or economic pressures associated with the Nitrate Directive.

EU production is more widely and significantly affected by CAP reform than by either the Nitrate Directive or the fertilizer tax. Livestock production declines under the Nitrate Directive, while the nitrogen tax only slightly reduces crop production. Only the Nitrate Directive is likely to reduce residual nitrogen to desired levels in regions where needed.

Based on a model of EU and world agriculture existing in 1986, the Nitrate Directive implies that the EU could become a net importer of livestock products, export more wheat and coarse grains, and import less corn and oilseeds. World livestock and corn prices could increase, but U.S. oilseed producers may export less at lower prices.

Based on the modeling estimates, CAP reform implies that pork and poultry production could increase and crop production could decrease. Exports of pork, poultry, and wheat could increase and imports of feed grains and oilseeds could increase. World prices could increase for all products except pork, poultry products, and wheat, and the United States could export more of the higher priced products.

The combination of the Nitrate Directive and CAP reform reduces both livestock and crop production in the EU. World livestock prices generally increase the most in this scenario, but world crop prices increase less than under CAP reform alone, because the combined Directive and CAP reform lowers EU feed demand. The combined policies affect U.S. livestock trade in ways similar to the effects of the Nitrate Directive, except trade of pork. In this scenario, U.S. grain exports increase to levels between those affected by either the Nitrate Directive or CAP reform.

Some technical relationships need to be refined in future research, some of which Veenendaal and Brouwer (1991) have recently addressed. Most importantly, subregional analysis is needed, because aggregation hides problems in large countries. A more detailed analysis of how the nitrogen cycle operates under varying soil and environmental conditions is necessary. Account also needs to be taken of nonagricultural sources of nitrogen, such as acid rain or the decay of trees and vegetation. And, the reliability of the nitrogen content coefficients needs to be established.

Some factors would be difficult to account for, even in a subregional analysis. Nonagricultural sources of nitrogen are not included. Although the contribution of agriculture to the nitrate problem may be brought into balance, it is not clear how much of the overall nitrate problem in water may have its source elsewhere, such as in acidic deposition or the decay of trees and vegetation. For example, the nitrogen content of straw is treated as uptake, but this straw does biodegrade, with some nitrogen exiting into the atmosphere and some returning to the soil. A similar problem occurs when nitrogen in manure vaporizes (termed "volatilization") and enters the atmosphere.

A comparison of other studies suggests some methodological areas of research. These include better accounting for input substitution, the flow of inputs, especially labor and capital between sectors, and the structure of the fertilizer industry.

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Appendix: Incorporating Inputs Into ST86 Using Joint-Production Theory

One limitation of ST86 is that it is a synthetic model, in that elasticities are not estimated but are obtained from a variety of published sources using different estimation techniques or based on expert opinion (Sullivan and others, 1989). Such a method may result in a system characterized by regional supply elasticities that are theoretically inconsistent with behavioral or technological relationships. Input demand elasticities are also not included in the standard model.

A more structured approach is based on duality theory (Ball, 1988). The dual, or so-called joint-products, approach provides theoretical restrictions on the behavior of both output supply and input demand equations that can be econometrically tested. This approach also explicitly accounts for the role of production technology in determining the degree of substitutability among inputs. Finally, it allows for the production of multiple outputs with multiple inputs that characterizes agriculture at the aggregate level.

Details of the joint production approach are published in Ball (1988) and Liapis (1990), but, in summary, this approach estimates the relationships of substitutability and complementarity among all inputs and outputs. The effects of a policy on multiple inputs and outputs are therefore identified. The inputs include fertilizer, real estate, two types of capital, machinery, hired labor, energy, and other inputs. Because the application of this approach to EU agriculture is still at a formative stage, only its impact on supply and input use is discussed.

When joint-production technology is incorporated into ST86, the fertilizer tax reduces the production of all commodities, compared with only reducing crop production, as in the standard ST86 model (app. fig. 1). Grain production decreases slightly more than 4 percent, while oilseed and livestock products decrease about 2 percent. The differences in supply response between the two approaches are relatively small, however.

The changes in crop and livestock production in response to CAP reform are less under the assumption of joint production than when the standard ST86 model is used (app. fig. 1). The increase in pork production is only 5 percent, compared with nearly 10 percent in the standard ST86. The production of oilseeds declines less than 5 percent, and grains decline about 7 percent, compared with about 40 percent and 15 percent in the standard ST86. The assumption of technology affects beef, eggs, and to a lesser extent, dairy.

With some exceptions, input usage does not change by great magnitudes in any of the scenarios (app. fig. 2). In the case of the Nitrate Directive, the use of all inputs increases less than 1 percent. With the fertilizer tax, the use of fertilizer declines by 20 percent, and the other inputs decline by less than 3 percent. Under CAP reform, all inputs except durable equipment decline. The declines are much greater than in the case of the fertilizer tax, with the exception of fertilizer itself.

The different results occur between the standard ST86 and the joint-products approach because of the consistent nature of the technological assumptions the latter approach imposed. As a result, own-price and cross-price supply elasticities differ between the two approaches. This appendix highlights the usefulness of applying the joint-production technology approach to the European Union and encourages both additional work on this topic as well as a critical evaluation of it. Additional research is continuing by Ball and others (1993).

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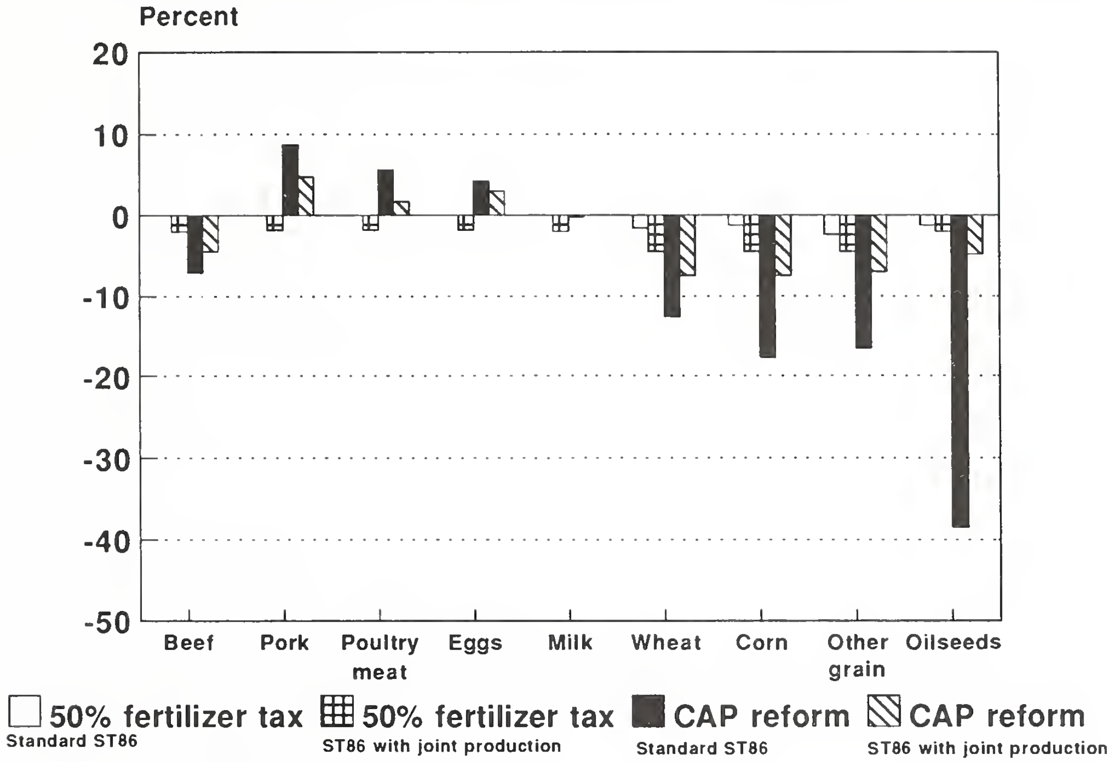
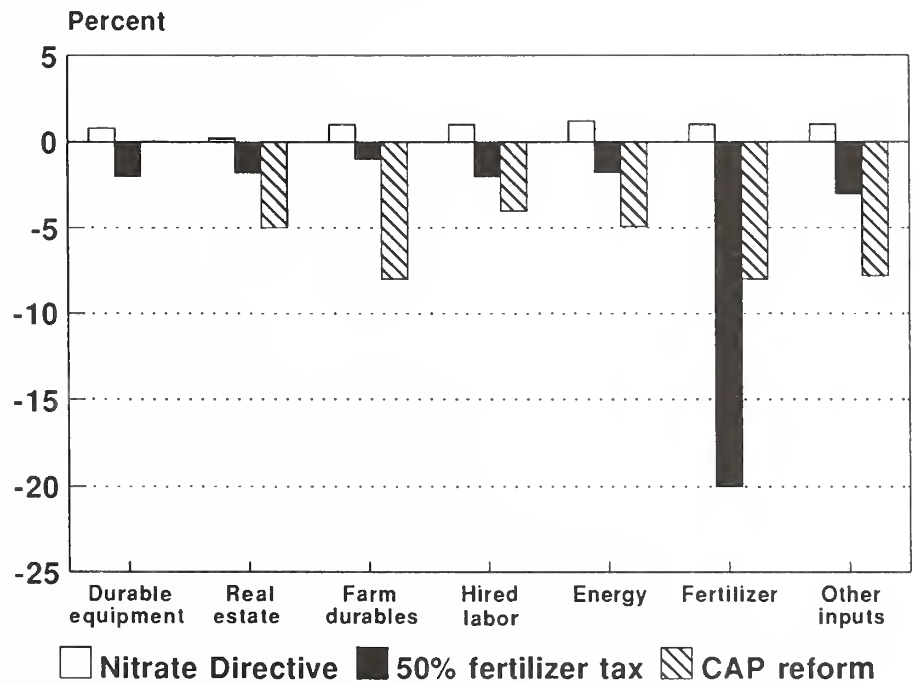
Appendix figure 1

EU supply changes with and without joint production technology



Appendix figure 2

Changes in levels of resource use due to selected policies using joint production technology



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